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In vitro Analysis of Tooth Roughness under Horizontal and Vertical Brushing

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Abstract **Introduction:** Tooth brushing is a crucial part of oral hygiene. It is essential to stop plaque formation and reduce the susceptibility to cavities. Brushing technique, frequency and duration of tooth brushing are important factors in plaque reduction. This is often quite difficult in children because it requires dexterity. Dental professionals need adequate information about children's oral hygiene to teach them and their parents. There are six methods of tooth brushing techniques. They differ in a number of aspects and are recommended for various age groups. **Aim:** This study aims to evaluate the effects of simulated horizontal and vertical tooth brushing on tooth surface roughness using medium bristle stiffness levels. **Method:** A total of 48 extracted human incisor teeth were divided into two experimental groups based on brushing technique (horizontal vs. vertical) and bristle stiffness (medium). Brushing simulation was conducted using an automated brushing machine, applying a standardized load and brushing duration. Surface roughness was measured using a profilometer. The collected data was tabulated in Excel. The data is represented with the help of bar graphs and statistically analysed with the help of SPSS software. The statistical tests done were Mean, Standard deviation and t -tests. **Results:** The p-value is far below 0.05, indicating that the difference between the vertical and horizontal values is statistically significant. The intervention or condition that changed between the pre and post measurements of horizontal brushing likely had a real and strong effect. **Conclusion:** Within the limitations of the study, it shows that vertical brushing technique is the most preferred brushing technique**.** Brushing technique significantly influence tooth surface roughness. Vertical brushing may be recommended for maintaining smoother tooth surfaces and minimizing abrasion.

Key Words Abrasion, Profilometer, Brushing, Vertical Strokes, Horizontal Strokes, Simulation, Tooth Roughness

INTRODUCTION

Cervical abrasion is a common form of Non-Carious Cervical Lesion (NCCL) characterized by the loss of tooth structure at the cervical margin. It is often attributed to mechanical factors such as tooth brushing habits. Understanding the impact of various brushing methods and tools on cervical abrasion is crucial to providing evidence-based preventive strategies.

DH is one of the most vexing dental problems, affecting people aged 20 to 50 [1]. The hydrodynamic theory explains the environmental, mechanical, thermal and chemical changes that cause fluid movement within the exposed dentinal tubules, stimulating the pulpal fibers and inducing transient sharp pain. Visual or tactile examination of the teeth is essential to elicit the characteristic DH by applying a stimulus to the affected tooth with standardized air-blast stimulation [1].

Morphological and histological features of the cervical region contribute to the region's disproportionately high rate of lesion development, where the tooth crown becomes more vulnerable to physical and chemical stimuli as the enamel thickness gradually decreases near the cementoenamel junction (CEJ) and the dentinoenamel junction. In its initial phases, the cervical abrasion appears clinically as a narrow horizontal groove on the buccal/labial surface of the tooth near the CEJ. It also has a polished surface with a glossy appearance, as well as tactile sensitivity to the path of the explorer [2].

Cervical Abrasion (CA) is defined as a pathological condition caused by abrasive agents on the tooth surface or any objects placed frequently between or on the teeth. Tooth wear-attrition, abrasion and erosion are considered Non-Carious Cervical Lesions (NCCLs), discomfort, sensitivity,

pain and loss of tooth vitality [3]. The etiology of cervical abrasion is multifactorial involving a complex interaction of various factors such as overzealous brushing technique, use of an abrasive agent. Other factors such as erosion and abfraction also contribute to varying degrees [3].

Since the abrasive process is rather slow, there is formation of secondary and tertiary dentin to protect the pulp. Sclerotic dentin is another protective response that has treatment implications. Retention of dental plaque, sensitivity, pulp damage and periodontal disease progression are few of the undesirable effects of CA. Treatment is aimed toward managing the symptoms, restoring the morphology of the teeth and treating soft tissue pathology. If untreated, pulpal exposure and infection, as well as periodontal deterioration are possible. Therefore, CA must be managed appropriately with suitable restorative procedures [4].

Several biological, chemical and behavioral functions can hasten the process leading to structural and functional loss of teeth. The cementum and dentin are more likely to be severely affected [5]. These are a group of lesions called noncarious cervical lesions presented as a wedge or V-shaped defect on the cervical region of the tooth, associated with gingival recession [5,6].

Many variables, including rough toothbrushing and the use of dentifrice with a high-abrasive component, may lead to tooth abrasion. Brushing causes lesions that are more noticeable in the incisor, canine and premolar regions than they are in the molar region [7].

Maintaining proper oral hygiene is essential for the prevention of dental caries and periodontal conditions, with toothbrushing being a fundamental component of routine oral care. Nevertheless, both clinical and epidemiological evidence have highlighted concerns regarding the negative consequences of incorrect brushing practices, particularly the development of cervical abrasion. This condition involves the pathological loss of tooth structure at the cervical region (near the gumline) and is typically attributed to mechanical wear rather than decay. Contributing factors include the application of excessive brushing pressure, use of toothbrushes with hard bristles and highly abrasive toothpaste formulations.

Cervical abrasion has been observed in various demographic groups, affecting individuals across different age ranges. Although structural changes in the tooth related to aging-such as increased dentin exposure-may play a role, inappropriate brushing habits continue to be a significant and adjustable risk factor. Despite numerous studies investigating the mechanical aspects of brushing, there remains a lack of consensus on the most effective brushing method, duration and frequency that can adequately clean teeth while minimizing damage. Furthermore, the interaction between mechanical forces and chemical influences, including abrasive agents in toothpaste and acidic components in the diet, deserves closer examination.

One major difficulty in evaluating cervical abrasion lies in distinguishing it from other forms of Non-Carious Cervical Lesions (NCCLs), such as erosion and abfraction. While abrasion is primarily mechanical, erosion results from the chemical breakdown of tooth structure due to acid exposure and abfraction is believed to stem from stress-induced microcracks caused by occlusal forces. The overlapping characteristics of these conditions complicate efforts to isolate toothbrushing as a primary cause, highlighting the need for well-controlled clinical and laboratory-based investigations.

Brushing force has emerged as one of the most extensively studied mechanical factors associated with cervical abrasion. Evidence suggests that applying too much pressure while brushing can accelerate the wear of dental surfaces, especially when combined with abrasive toothpaste. Although the use of soft-bristled toothbrushes is generally recommended to reduce mechanical stress, debates persist regarding their efficacy in comparison to brushes with medium or hard bristles. Additionally, the choice between manual and electric toothbrushes introduces further complexity. Some studies advocate for electric brushes with built-in pressure sensors to help control brushing force, while others caution that high-speed oscillatory movements may also contribute to enamel and dentin loss under specific circumstances.

Brushing Techniques and Cervical Abrasion

Eccles suggested the term “tooth surface loss” when a single etiological factor was difficult to identify. However, Smith and Knight advocated the term “tooth-wear” to embrace all three processes of abrasion, attrition and erosion.

Smith and Knight presented the concept of measuring tooth wear fundamentally, irrespective of the etiology, which paved the way for other indices. The Tooth Wear Index is a comprehensive framework whereby every one of the four surfaces (buccal, cervical, lingual and occlusal-incisal) of all teeth present is scored for wear, independent of etiology. However, the drawback of this index was that it required computer assistance and was time-consuming [6].

Ali *et al.* [6] pioneered a new simplified version of the Tooth Wear Index where the scoring was dichotomized into the presence or absence of dentine, with even cupping of dentine scoring one. Some debate still exists regarding the significance of dentinal cupping when exposed dentine does not relate to significant amounts of tissue loss [6].

Several studies have investigated the impact of brushing techniques on cervical abrasion. Horizontal brushing has been frequently associated with higher rates of abrasion due to the repetitive back-and-forth motion at the cervical region. A study by Addy *et al.* [8] demonstrated that horizontal brushing with excessive force significantly increased cervical wear compared to circular and vertical techniques.

A recent study by Grender *et al.* [9] explored the effect of modified Bass technique in preventing cervical abrasion. The findings indicated that the modified Bass technique, which involves gentle vibratory motion, resulted in minimal cervical wear over a six-month follow-up period.

A systematic review by Marschner *et al.* [10] reinforced that the horizontal brushing technique combined with abrasive toothpaste accelerates cervical wear. The study emphasized that brushing with low-abrasive toothpaste and gentle pressure reduced the risk of cervical abrasion.

A clinical trial by Joiner *et al.* [11] evaluated the effect of brushing technique on cervical abrasion and found that vertical brushing with soft-bristle toothbrushes produced significantly lower cervical wear compared to horizontal techniques.

Factors Influencing the Severity of Cervical Abrasion

Toothbrush type: The tubules in sensitive dentin are said to be open between the exposed dentinal surface and the pulp and are wider than those in no sensitive dentin. Furthermore, the number of tubules in the sensitive dentin is eightfold wider than the no sensitive dentin [7]. The factors associated with cervical abrasion include overzealous tooth brushing using hard bristles and the use of abrasive toothpaste [14-17]. It is stated that there is no ideal treatment for DH, even in the case of a combination of diverse protocols [18].

Manual and electric toothbrushes have been compared in various studies. While electric toothbrushes provide more consistent brushing pressure, some studies suggest they may reduce cervical abrasion when used with pressure control features.

Future Scope

A toothbrush was successfully developed using a natural composite filament made from neem fiber, neem powder and PLA. Analysis of its functional groups, crystalline structure and morphology revealed that the neem-infused bristles help reduce oral diseases and improve teeth whitening. FTIR results showed peaks linked to cellulose, carbohydrates and nimbin-an active compound known for its oral health benefits. The high amorphous content (89%) suggests reduced crystallinity, supporting the natural antibacterial properties of neem. This eco-friendly toothbrush blends modern dental care with neem's natural antimicrobial effects, offering promising benefits for oral health and sustainability [19-21].

Brushing Frequency, Duration, Force

Higher brushing frequency and prolonged brushing sessions increase mechanical stress on tooth surfaces. Several studies have reported a positive correlation between brushing frequency and cervical wear. Brushing force is a critical factor in cervical abrasion. Excessive force, particularly when combined with abrasive toothpaste, exacerbates cervical wear [11].

Materials and Methods Selection of Teeth

Forty Eight central incisors were selected and decoronated (Figure 1). The coronal portion was mounted on a silicone mould with standard dimensions.

Selection of Toothbrushes

Commercially available medium bristle variety toothbrushes were purchased from the local market for the study. The toothbrushes were fixed tightly with the help of screws in the automated brushing machines.

Roughness Evaluation

The baseline roughness was evaluated using a Stylus Profilometer (Figure 3). The Profilometer is a device that is used to measure the surface roughness changes. It produces a trace using the digital and analogue hardware and software. The Roughness average (Ra), The Roughness peak(Rz), The Root Mean Square Roughness (Rq) were obtained for the mounted tooth specimens (Figure 2).

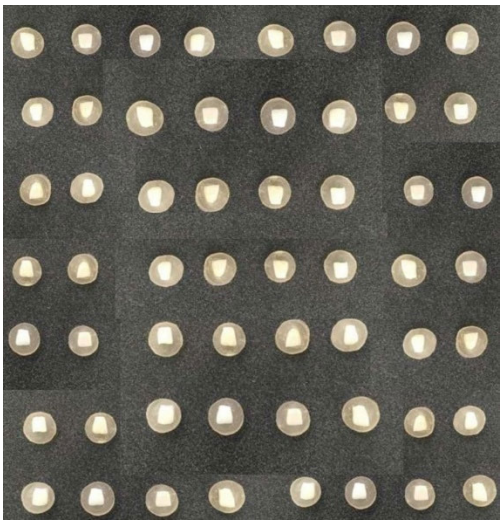

Figure 1: Forty Eight central incisors non carious were chosen for the study

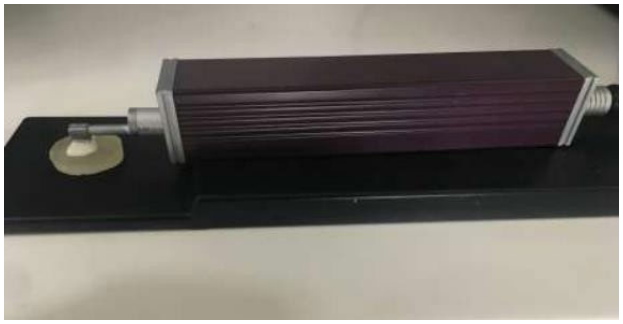

Figure 2: The pre roughness of the tooth sample was calculated

Figure 3: Roughness average calculated using the stylus profilometer

Figure 4: Sd Mechatronik Brushing Simulator Used For Brushing The Teeth Samples.

Duration and Frequency of Brushing

The tooth samples were mounted in the SD MECHATRONIK BRUSHING SIMULATOR (Figure 4) Which consists of 20,000 cycles (Linear x5000, clockwise-5000 and anticlockwise-5000) After which the pre and post roughness mean were calculated and the change in the roughness was compared. Procedure The profilometric analysis was done for the mounted tooth samples before tooth brushing and the mean surface roughness was calculated.

Brushing Simulation

- Brushing was conducted using an automated brushing machine to ensure consistency in stroke application
- Each toothbrush was replaced every three months to simulate real-world conditions of wear and effectiveness loss
- Brushing was performed under a controlled pressure of 100 g, with a stroke frequency of 180 strokes/min
- The toothbrushes used were standard commercially available medium-bristled brushes
- The brushing simulation was conducted for a total period of one year, with toothbrushes changed every three months
- Over the course of the study, each sample underwent a total of 131,400 brushing strokes, corresponding to the estimated number of strokes a person would perform in a year of daily brushing at a rate of 3 strokes per second

Outcome Measure

- Tooth surface roughness was measured using a non-contact profilometer at baseline and at the end of the one-year period
- Measurements were taken at three points and the mean value was recorded for statistical analysis

The Ra value (Roughness Average) is a common measure of surface roughness, which quantifies the average height deviation of a surface profile from a mean line over a specified length. The Ra value is used in various fields, including materials science and engineering, to assess the smoothness or roughness of a surface.

Here's a general idea of how different Ra values translate into surface roughness:

- **Ra = 0.01-0.05 µm:** Extremely smooth, often seen in precision engineering, like polished metal surfaces in aerospace or semiconductor manufacturing
- **Ra = 0.1-0.3 µm:** Smooth, used in high-precision machinery, fine polishing of metals or polished glass surfaces
- **Ra = 0.5-1.0 µm:** Lightly rough, typical of ground steel or lightly machined surfaces
- **Ra = 1.0-3.2 µm:** Moderate roughness, commonly found in machined parts, industrial steel or castings
- **Ra = 5.0-10.0 µm:** Rough surfaces, such as those found in typical castings, welds and some structural components
- **Ra = 10.0-25.0 µm:** Very rough, seen in heavily casted parts or surfaces where a significant amount of machining is done
- **Ra>25.0 µm:** Extremely rough, often a result of processes like sandblasting or large- scale casting operations

RESULTS AND DISCUSSION

Toothbrush may be a well-known tool in oral care. Familiarity of youngsters with this device is vital. Effective

tooth brushing aids in the management of cavity and periodontitis. Dentists and Dental assistants need adequate information about children's oral hygiene to teach them and their parents. Also tooth brushing twice daily under parent's supervision is suggested [22].

The oldest toothbrushing method was described in 1913 by Fones and is suggested mainly for youngsters. The Bass technique places emphasis on the removal of plaque from above and slightly below the gingival margin. Bass had been changed to the Modified Bass where the bristle position and predominantly horizontal brush movements within the Bass method are retained but vertical and sweeping motions to make circles are added. The Stillman technique is analogous to the Bass technique. The vertical motions of the Stillman technique could also be combined with the Bass, as prescribed for the Modified Bass. Charters suggested angling the comb head at 45° coronaly to the margin instead of apically. Vibratory and slight rotary movement is then applied before moving to the subsequent group of teeth. An abnormal frenum may be an additive factor to plaque accumulation and may cause inhibition to proper tooth brushing. The Scrub technique is the most simple technique, with the toothbrush held parallel to the gingiva and horizontal motions to scrub the gingival crevice in an ordered fashion. There are some modification techniques such as Hirschfeld's technique which is a modification of the Fone's technique where the circular motion is smaller and concentrated over the gingival crevice. Frequency and duration of brushing are usually included with recommendations concerning the tactic of toothbrushing for children [22].

Modified Bass technique emerged as the most commonly recommended brushing method for patients aged 13 to 17 years. Oral hygiene instructions should be tailored to align with a child's developmental level and motor coordination. It is important to account for differences in brushing ability, particularly among younger children [22].

Fones technique emerged as the most commonly recommended brushing method by dentists for children aged 6 to 12 years, regardless of gender. The Modified Bass technique was the next most preferred. Ensuring proper oral hygiene during the mixed dentition stage is crucial and demands ongoing reinforcement [23].

Participants who regularly used ultrasonic toothbrushes showed a noticeable reduction in oral and salivary bacterial counts compared to those in the control group. However, proper guidance and monitoring are essential for individuals using ultrasonic toothbrushes [24].

She indicated that toothbrushes used by individuals with gingivitis had higher levels of bacterial contamination compared to those used by individuals with healthy gums. The most commonly identified microorganisms were Staphylococcus aureus and Streptococcus mutans. Toothbrushes play a significant role in the transmission of microorganisms, potentially increasing the risk of infection. Therefore, it is essential for dentists to take an active role in educating patients about the proper selection, storage, hygiene and timely replacement of toothbrushes [25].

A toothbrush is a principle instrument that helps in maintaining proper hygiene and oral care. Based on the different bristle diameters the tooth brushes have been categorized as soft (0.2 mm), medium (0.3 mm) and hard (0.4 mm). Choosing the right toothbrush plays an important role in maintaining oral hygiene. Apart from choosing the right toothbrush, proper usage of the toothbrush should also be taken into consideration, as improper brushing may lead to the soft and hard tissues of the teeth. This may lead to conditions such like abrasion. Abrasion is the process in which the enamel erodes due to the force applied on teeth, improper brushing can also be caused for abrasion. Toothbrushes with different functions have been developed for oral health management. The factors that influence the surface roughness of teeth are the brushing methods, frequency, duration of brushing, bristle diameter, shape, force of brushing direction of brushing, number of bristles per tuft and its management [26].

Electric toothbrushes may be less effective for blind children due to their limited tactile feedback, which makes it challenging for them to feel the pressure and identify the areas being cleaned. This can hinder effective brushing techniques and result in inadequate plaque removal. Additionally, the complexity of electric toothbrushes- often relying on visual cues and features like timers and sensors- creates difficulties for blind children in establishing consistent routines and gaining confidence in their use. Caregivers and healthcare providers play a crucial role in supporting the unique needs of blind children by developing tailored oral care solutions, including the use of manual brushes and adaptive tools such as Braille instructions [27].

Statistical Analysis

Vertical:

- Mean Ra difference = -0.025
- Sample size (n) = 24
- Standard deviation (SD) ≈ 0.0537 (Table 1)

Horizontal:

- Mean Ra difference = -1.455
- Sample size (n) = 24
- Standard deviation (SD) ≈ 0.0858 (Table 2)

Independent t-test was applied for Statistical Analysis

- Mean Difference (Horizontal - Vertical) = 1.430
- Standard Error (SE) = 0.02066
- t-value = 69.2
- Degrees of Freedom (df) = 46
- p-value = < 0.0001 (highly significant) (Figure 6-9)

Table 1: Brushing Simulation with Vertical Strokes

Group A	Sample Size	Mean Surface Roughness (Ra, µm)	Standard Deviation	
Incisor teeth: Pre Vertical Brushing	24	1.3518	0.0099	
Incisor teeth: Post Vertical Brushing	24	1.3771	0.053	
Group A: Vertical Brushing Sample Size	Pre Brushing Mean Surface Roughness (Ra, µm)	Post Brushing Mean Surface Roughness (Ra, µm)	Mean Surface Roughness (Ra, µm) Difference	Standard Deviation (SD) Mean Difference
24	1.351	1.377	0.025	≈ 0.0537

Table 2: Brushing Simulation with Horizontal Strokes

Group B	Sample Size	Mean Surface Roughness (Ra, µm)	Standard Deviation	
Incisor teeth: Pre Horizontal Brushing	24	1.958	0.065	
Incisor teeth: Post Horizontal Brushing	24	3.413	0.056	
Group B: Horizontal Brushing Sample Size	Pre Brushing Mean Surface Roughness (Ra, µm)	Post Brushing Mean Surface Roughness (Ra, µm)	Mean Surface Roughness (Ra, µm) Difference	Standard Deviation (SD) Mean Difference
24	1.958	3.413	1.455	≈ 0.0858

Figure 5: Horizontal brushing-stereomicroscope 30X image

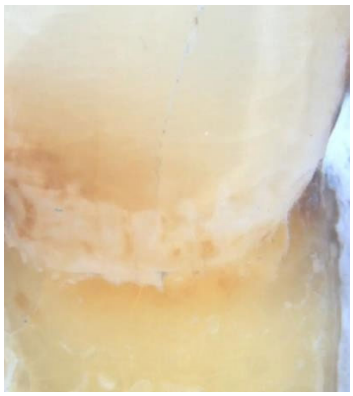

Figure 6: Vertical brushing-stereomicroscope 30X image

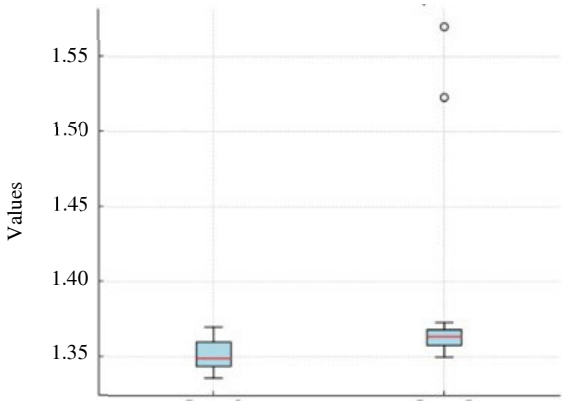

Figure 7: Box Plot For Vertical Pre and Vertical Post

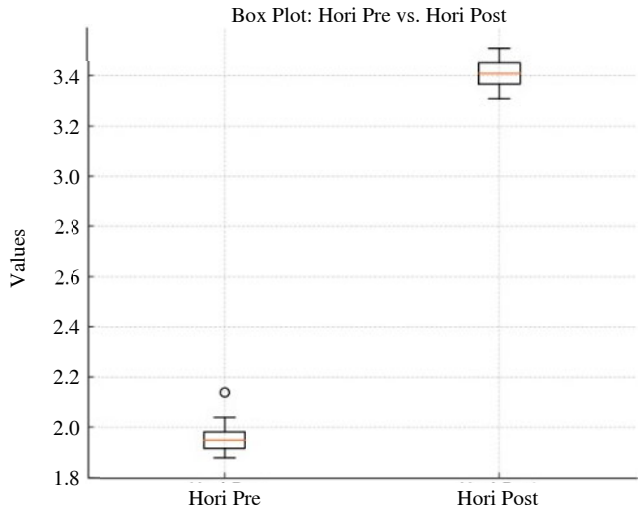

Figure 8: Box Plot for Horizontal Pre and Horizontal Post

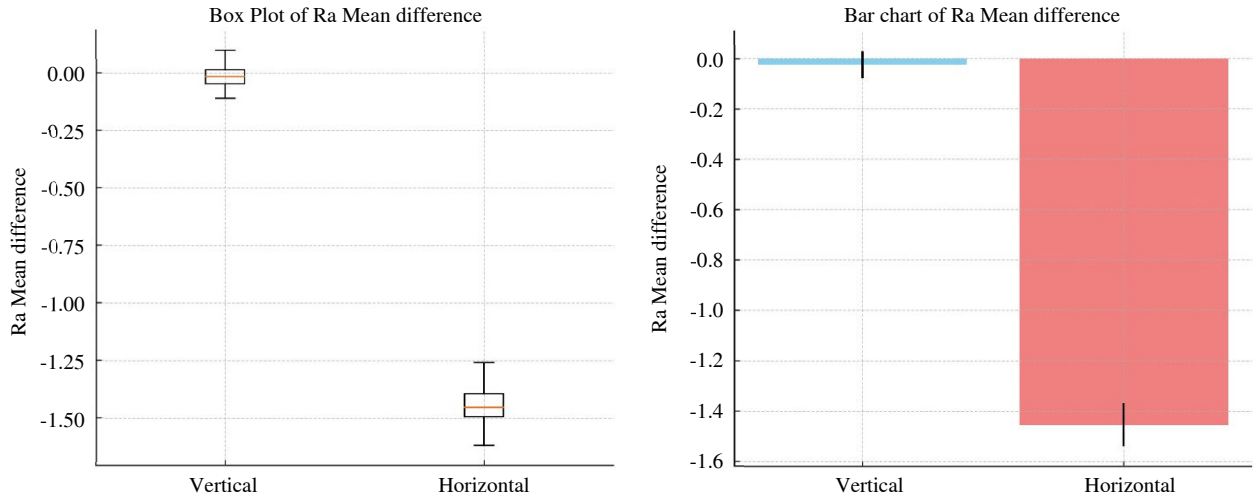

Figure 9: Box Plot for Mean differences Vertical brushing and Horizontal brushing

Table 3: Final Results

Comparison	Value
Mean Difference (Vertical - Horizontal)	1.430
Standard Error (SE)	0.02066
t-value	69.2
Degrees of Freedom (df)	46
p-value	<0.0001
Significance	Statistically significant

p-value

Using the t-value (69.2) and df = 46, the p-value will be extremely small, essentially <0.0001 (Table 3).

CONCLUSIONS

Within the limitations of the study, it shows that vertical brushing technique is the most preferred brushing technique. Brushing technique significantly influence tooth surface roughness. Vertical brushing may be recommended for maintaining smoother tooth surfaces and minimizing abrasion. There is a highly significant difference between the vertical and horizontal Ra mean differences. The p-value indicates statistical significance.

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